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SOME EFFECTS OF AIRPLANE OPERATIONS AND THE ATMOSPHERE ON SONIC-BOOM SIGNATURES

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SUMMARY

The information of the paper is in the form of a status report on the state of knowledge of sonic-boom phenomena, dealing first with the pressure buildups in the transonic speed range and with the lateral extent of the pattern in steady flight for quiescent atmospheric conditions. There are also discussions of recent data from flight-test studies relating to atmospheric dynamic effects on the sonic-boom signatures. The acceleration and lateral-spread phenomena appear to be fairly well understood and predictable for current and future aircraft. Variations in the sonic-boom signature as a result of the effects of the atmosphere can be expected during routine operations. From the data evaluated to date, very similar variations in pressure signatures are noted for both fighter and bomber aircraft.

INTRODUCTION

The scope of the material to be discussed in this paper is illustrated by the sketches of figure 1. Shown schematically in the figure is an airplane flight track extending from subsonic to supersonic speeds. Beneath the flight track are shown sketches of the shock-wave impingement patterns and the associated distributions of N-wave pressures, both along the track and perpendicular to it. The information of the paper is in the form of a report on the state of knowledge of sonic-boom phenomena, dealing first with the pressure buildups in the transonic speed range (see refs. 1 to 10) and with the lateral extent of the pattern in steady flight for quiescent atmospheric conditions (see refs. 11 to 14). Also there are discussions of recent data from flight-test studies relating to atmospheric dynamic effects on the sonic-boom signatures (refs. 9, 10, and 14 to 18).

SYMBOLS

M	Mach number
Δp	sonic-boom overpressure, lb/sq ft
Δp_o	sonic-boom overpressure at ground level, lb/sq ft
$\left(\Delta p_{o,calc}\right)_{max}$	calculated maximum sonic-boom overpressure on ground track, lb/sq ft

EFFECTS OF ACCELERATED FLIGHT

Certain maneuvers of an aircraft in which longitudinal, lateral, or normal accelerations occur can result in pressure buildups on the ground that are commonly referred to as "superbooms." One important consideration is the shape and size of these superboom areas on the ground. Such areas are shown in figure 2 for some common flight maneuvers. It should be pointed out that although the aircraft and shock waves are moving, these superboom areas are fixed and do not move with the aircraft. The longitudinal acceleration case is illustrated at the top of the figure. As indicated in the sketch by the thin shaded areas, superbooms occur over relatively small expanses on the ground. The dimensions are such that total superboom area (area of shading only) is approximately one square mile. The pressure buildups in these shaded areas are believed to be a function of the rate of acceleration of the aircraft, but for a practical operating range are approximately two times the corresponding steady-flight values. Also of possible concern in the operation of supersonic aircraft are such maneuvers as horizontal turns and pushovers as might occur during changes in course and airplane attitude. In these latter instances the ground patterns of pressure buildups are different in shape as indicated in figure 2, and because of the higher accelerations involved the buildup factors may tend to be higher (values up to 4.0 have been measured) and the areas smaller than for the case of longitudinal acceleration.

An extensive series of ground-pressure measurements has been made for longitudinal aircraft accelerations from Mach 0.9 to about Mach 1.5 at a constant altitude of 37,200 feet with a special array of microphones extending about 23 miles along the ground track. The measured data points from three such acceleration flights are shown at the bottom of figure 3. The data at the zero position represent the so-called superboom conditions where pressure buildups occur. The data for the three separate flights were normalized by plotting the highest measured overpressure values at this zero position. The direction of the aircraft is from left to right, as indicated by the sketches at the top along with corresponding tracings of measured signatures. The data points in the figure represent peak overpressures as defined in the sketch. The low value points to the left of the figure represent noise and are observed as rumbles. The high value points near the center of the figure correspond to measurements that are very close to the focus point, and thus represent what are conventionally described as superbooms. To the right of the focus point are two distinct sets of measurements which relate to the region of multiple booms. For convenience in illustrating the trends of the data, solid and dashed lines are faired through the data points. The data points that cluster about the solid curve relate to the first signature to arrive, in all cases, and this eventually develops into the steady-state signature. The data points that cluster about the dashed curve relate, in all cases, to the second signature to arrive. These values generally decrease as distance increases, and eventually this second wave ceases to exist because of the refraction effects of the atmosphere.

The highest overpressures are measured in a very localized region. These values are as high as 2.5 times the maximum value observed in the multiple-boom region and are thus in general agreement with the measured results for other lower altitude tests of reference 9. The main multiple-boom overpressure values are of the same order of magnitude as those predicted for comparable steady-state flight conditions. Available overpressure prediction methods (see refs. 2, 3, and 15) give good agreement in the multiple-boom region, but are not considered reliable in the superboom region.

The location of the superboom and multiple-boom regions are readily predictable (see refs. 3 and 15) provided such information as flight path, altitude, and acceleration rate of the aircraft is available. Based on experience, it is believed that the superboom can be placed at a position on the ground to within about ±5 miles of the desired location. The prediction of the location of the superboom can be improved if more detailed weather information is available.

LATERAL-SPREAD PATTERNS

With regard to the steady-flight conditions, some recent experiments have also been conducted in an effort to define more exactly the pressure distribution near the extremity of the shock-wave pattern on the ground. Some sample data are shown in figure 4. Particular emphasis was placed on the region where a grazing condition exists because of atmospheric refraction, as suggested by the ray-path sketch at the top of the figure. Flights were made at altitudes of 52,200 and 37,200 feet and Mach numbers of 2.0 and 1.5, respectively, during quiescent atmospheric conditions, and the results are compared with theory in the data plots at the bottom. The results from the flight at 52,200 feet and a Mach number of 2.0 show that the pressures are generally highest on the track as predicted by theory (ref. 13), and decrease generally as distance increases. The fact that measurements were obtained beyond the theoretically predicted cutoff distance by the method of reference 13 led to more definitive studies at 37,200 feet and a Mach number of 1.5. (Solid symbols indicate that no boom was observed.) These data, which were obtained from four flights involving various displacement distances of the airplane from the overhead position, are similar and, in fact, indicate measured signals as much as 15 miles beyond the predicted cutoff distance.

A better understanding of this phenomenon may be obtained from examination of some sample waveforms based on measurements at various distances. Sharply defined shock-wave-type signatures exist generally for the region predicted by the calculations. Near the predicted lateral cutoff the rise times are noticeably longer. At distances beyond the predicted cutoff, the signatures lose their identity and associated observations indicate the existence of rumbles, as described previously. It is believed that these rumbles are the result of acoustic waves which either arrive ahead of the shock waves as illustrated in figure 3 of reference 19 or are noise which emanates from the extremity of the shock wave as it propagates through the air in the vicinity of the measuring stations.

OTHER EFFECTS OF THE ATMOSPHERE

The propagation of shock waves through the atmosphere may involve the dynamics of the atmosphere as well as the gross refraction effects just described. The data of figure 5 were derived from an accurately calibrated and oriented array of matched microphones along the ground track of the aircraft (ref. 18). The variations in the wave shapes measured during one steady flight of a fighter aircraft are sketched in for the appropriate measurement locations. A wide variation in wave shape occurs even over a distance on the ground of a few hundred feet. This variation in wave shape which is associated with changes in atmospheric and aircraft operating conditions resulted in substantial variations in the peak ground overpressure, the larger values being associated with the sharply peaked waves and the lower values with the rounded-off waves. It is believed that in this case atmospheric effects dominate. Recent analytical studies made under contract have suggested that the effects of the higher altitude disturbances are much less important than those of the lower altitudes (refs. 10, 14, 15, and 17).

Recent flight experiments have pointed to the fact that disturbances in the first few thousand feet of the atmosphere may be most significant in affecting the shapes of the sonic-boom signatures measured at the ground. The results are illustrated by the data of figure 6. Shown in the figure is temperature plotted against altitude as determined from wiresonde and rawinsonde soundings taken during the times of the flights. The filled symbols represent the type of temperature profile existing for the morning flights whereas the open symbols apply to the afternoon flight. It may be seen that the temperature conditions of the upper atmosphere do not vary appreciably during the morning and afternoon. On the other hand, in the first few hundred feet of the lower atmosphere, the temperature profile varies markedly. In the morning, a temperature inversion exists during which time the surface layer of the atmosphere is quiescent. Later in the day, as the surface temperature increases, the temperature profile may change to the extent that a superadiabatic lapse-rate condition can exist as indicated. For such a temperature profile, the surface layer of the atmosphere is inherently unstable and severe thermal-induced turbulence may be generated. There is a strong correlation between the type of signature measured and the existing temperature profile in the lower atmosphere. Consistent N-wave types of signatures were measured when the lower atmosphere was quiescent, whereas large variations in the shape of the signatures were measured when the lower atmosphere was considered to be unstable.

A further indication of the manner in which the atmosphere can affect the sonic-boom signature is given in figure 7. Shown in the figure are sample measured signatures from the same measuring station for two aircraft of the same type at similar flight conditions along similar flight tracks about 7,500 feet apart. The measured signatures as illustrated at the bottom of the figure indicate variations in shape. It should be noted that in this case the waves are traveling through essentially the same segment of the atmosphere but at slightly different times (approximately 5 seconds). The physical characteristics of the atmosphere or operating conditions of the airplanes have apparently changed sufficiently in that short period of time to produce the variations shown. (See refs. 9 and 16.) It is believed that in this case atmospheric effects dominate.

Measurements similar in nature to those of figures 5, 6, and 7 have been made at specific measuring points for a large number of supersonic flights, and the results are in good qualitative agreement. Some samples of these latter data are shown in figure 8. Sonic-boom signatures for a fighter aircraft are shown at the left (see ref. 18). These signatures vary widely from sharply peaked waves at the top to rounded-off waves of sinusoidal appearance at the bottom. Such results are very similar to those shown in figures 5, 6, and 7 for conditions of highly turbulent air in the lower atmosphere. The signatures on the right-hand side of the figure have been recently obtained for bomber aircraft and have a noticeably longer wavelength or time duration. The main distortions of the waves in each case are associated with the rapid compression phases, and these distortions are of the same general nature for both short and long wavelengths. The data of figure 8 relate to specific measuring stations for several different aircraft flyovers.

Because of the large number of data points available for a range of flight conditions, it was possible to make statistical analyses of the variations of overpressure. Samples of the overpressure variation data are given in figure 9 as relative cumulative frequency distributions and histograms showing probability of occurrence. In the left-hand plot of the figure are shown overpressure distributions for a fighter aircraft, and in the right-hand plot are similar data for a bomber aircraft. The probability of equaling or exceeding a given ratio of the measured overpressure value to the maximum predicted value for the respective steady flight conditions (which occurs on the ground track) is shown. All the data have been plotted on log normal scales, and straight lines have been faired through the data points as an aid in interpretation. For this type of presentation, all the data points would fall on a straight line if the logarithms of the data fitted a normal distribution. For the fighter aircraft, data were obtained on the ground track and at distances up to 10 miles from it; a wider variation in the overpressures occurred for the more remote stations. In the case of the bomber aircraft, fewer data points were available for analysis and, hence, the statistical sample is not as reliable. Based on the data available, the variation in overpressures for the bomber data, which have markedly longer wavelengths, is noted to be only slightly less than that for the fighter aircraft. Another point to note is that some of the pressure buildups due to atmospheric effects are of the same order of magnitude as those associated with the superboom phenomena.

CONCLUDING REMARKS

In conclusion, some recent results obtained with the aid of fighter and bomber aircraft have been presented in an attempt to show the significance of the atmosphere and aircraft operation on sonic-boom exposures. The acceleration and lateral-spread phenomena appear to be fairly well understood and predictable for current and future aircraft. Variations in the sonic-boom signature as a result of the effects of the atmosphere can be expected during routine operations. From the data evaluated to date, very similar variations in pressure signatures are noted for both fighter and bomber aircraft.

REFERENCES

1. Maglieri, Domenic J.; and Lansing, Donald L.: Sonic Booms From Aircraft in Maneuvers. NASA TN D-2370, 1964.
2. Lansing, Donald L.: Application of Acoustic Theory to Prediction of Sonic-Boom Ground Patterns from Maneuvering Aircraft. NASA TN D-1860, 1964.
3. Lansing, Donald L.; and Maglieri, Domenic J.: Comparison of Measured and Calculated Sonic-Boom Ground Patterns Due to Several Different Aircraft Maneuvers. NASA TN D-2730, 1965.
4. Lina, Lindsay J.; and Maglieri, Domenic J.: Ground Measurements of Airplane Shock-Wave Noise at Mach Numbers to 2.0 and at Altitudes to 60,000 Feet. NASA TN D-235, 1960.
5. Warren, C. H. E.: The Propagation of Sonic Bangs in a Nonhomogeneous Still Atmosphere. Paper No. 64-547, Intern. Council Aeron. Sci., Aug. 1964.
6. Lilley, G. M.; Westley, R.; Yates, A. H.; and Busing, J. R.: Some Aspects of Noise From Supersonic Aircraft. J. Roy. Aeron. Soc., vol. 57, no. 510, June 1953, pp. 396-414.
7. Rao, P. Sambasiva: Supersonic Bangs. Aeron. Quart., vol. VII.
   Part 1. pt. I, Feb. 1956, pp. 21-44.
   Part 2. pt. II, May 1956, pp. 135-155.
8. Kerr, T. H.: Experience of Supersonic Flying Over Land in the United Kingdom. Rept. 250, AGARD, North Atlantic Treaty Organization (Paris), Sept. 1959.
9. Hubbard, Harvey H.; Maglieri, Domenic J.; Huckel, Vera; and Hilton, David A.: Ground Measurements of Sonic Boom Pressures for the Altitude Range of 10,000 to 75,000 Feet. NASA TR R-198, 1964.

10. Anon.: Proceedings of NASA Conference on Supersonic-Transport Feasibility Studies and Supporting Research - September 17-19, 1963. NASA TM X-905, 1963.

11. Lina, Lindsay J.; Maglieri, Domenic J.; and Hubbard, Harvey H.: Supersonic Transports - Noise Aspects with Emphasis on Sonic Boom. 2nd Supersonic Transports (Proceedings). S.M.F. Fund Paper No. FF-26, Inst. Aeron. Sci., Jan. 25-27, 1960, pp. 2-12.

12. Maglieri, Domenic J.; Parrott, Tony L.; Hilton, David A.; and Copeland, William L.: Lateral-Spread Sonic-Boom Ground-Pressure Measurements From Airplanes at Altitudes to 75,000 Feet and at Mach Numbers to 2.0. NASA TN D-2021, 1963.

13. Randall, D. G.: Methods for Estimating Distributions and Intensities of Sonic Bangs. R. & M. No. 3113, British A.R.C., 1959.

14. Kane, Edward J.; and Palmer, Thomas Y.: Meteorological Aspects of the Sonic Boom. SRDS Rept. No. RD64-160 (AD 610 463), FAA, Sept 1964.

15. Friedman, Manfred P.: A Description of a Computer Program for the Study of Atmospheric Effects on Sonic Booms. NASA CR-157, 1965.

16. Maglieri, Domenic J.; and Parrott, Tony L.: Atmospheric Effects on Sonic-Boom Pressure Signatures. Sound, vol. 2, no. 4, July-Aug. 1963, pp. 11-14.

17. Hubbard, Harvey H.; and Maglieri, Domenic J.: Noise and Sonic Boom Considerations in the Operation of Supersonic Aircraft. Paper No. 64-548, Fourth Congress of the International Council of Aeronautical Sciences, Paris, France, August 1964.

18. Hilton, David A.; Huckel, Vera; Steiner, Roy; and Maglieri, Domenic J.: Sonic-Boom Exposures During FAA Community-Response Studies Over a 6-Month Period in the Oklahoma City Area. NASA TN D-2539, 1964.

19. Friedman, Manfred P.; and Chou, David C.: Behavior of the Sonic Boom Shock Wave Near the Sonic Cutoff Altitude. MIT Tech. Rept. 109, March 1965.

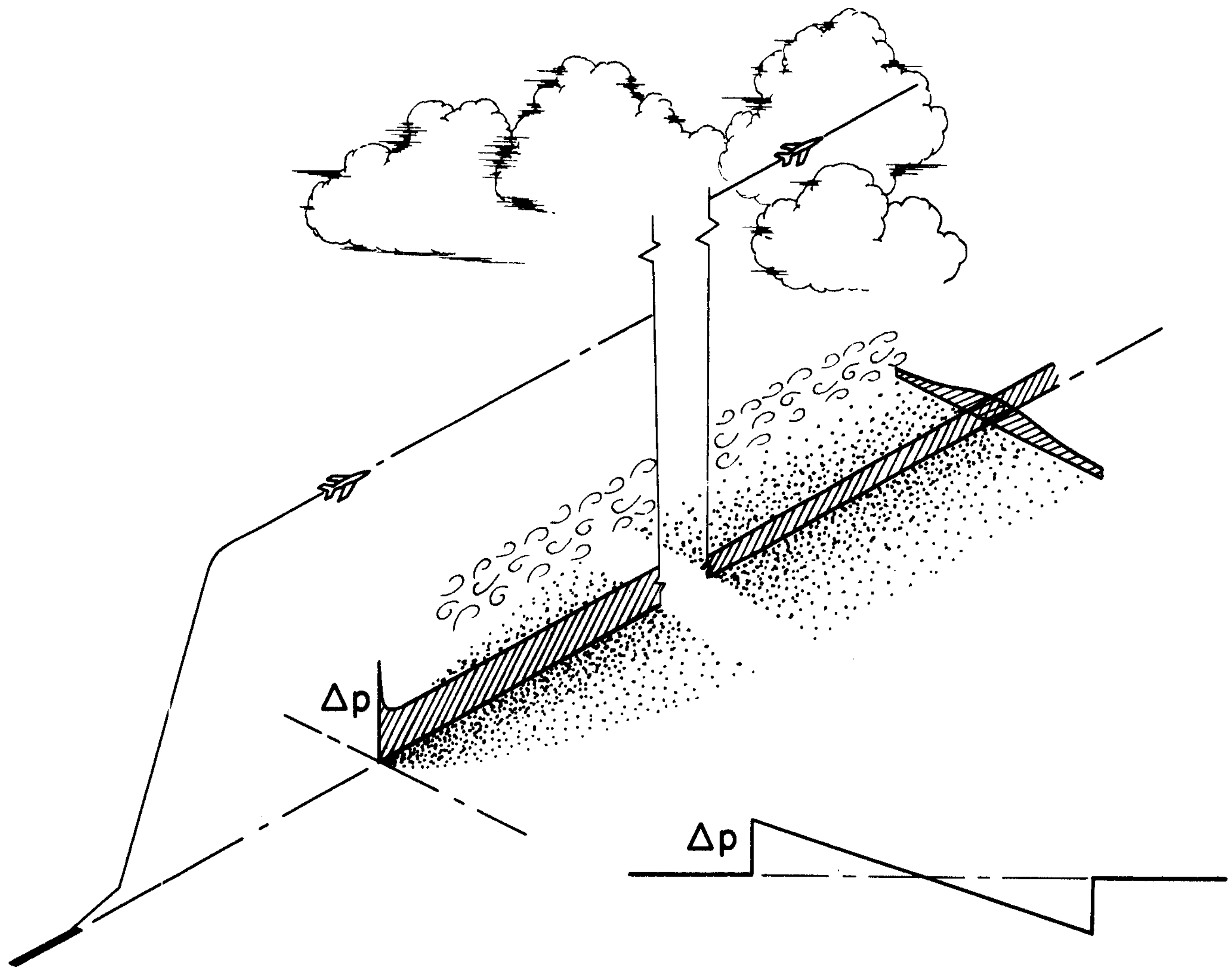


Figure 1.- Sonic-boom ground pressure patterns.

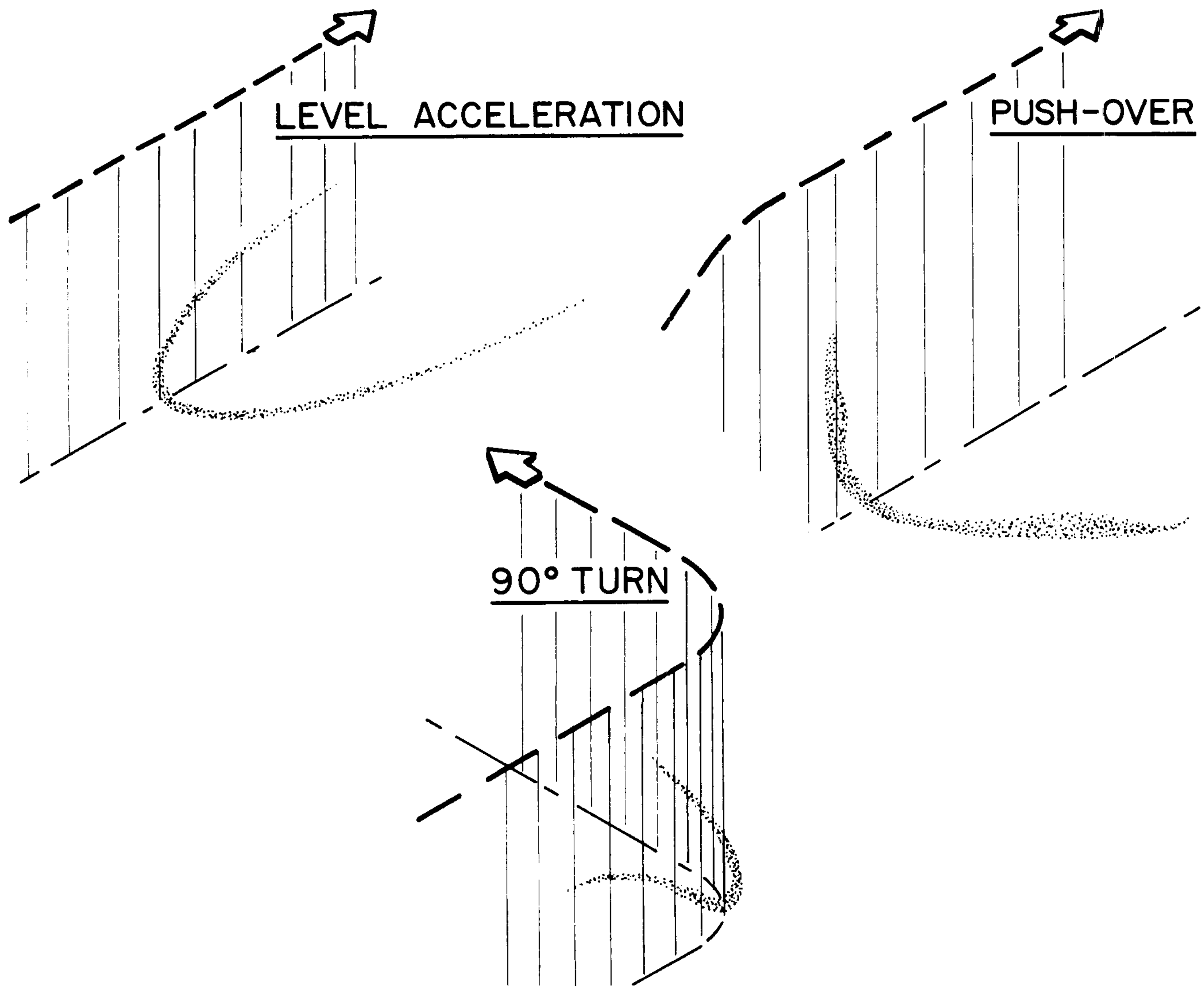


Figure 2.- Areas on the ground exposed to superbooms resulting from three different aircraft maneuvers.

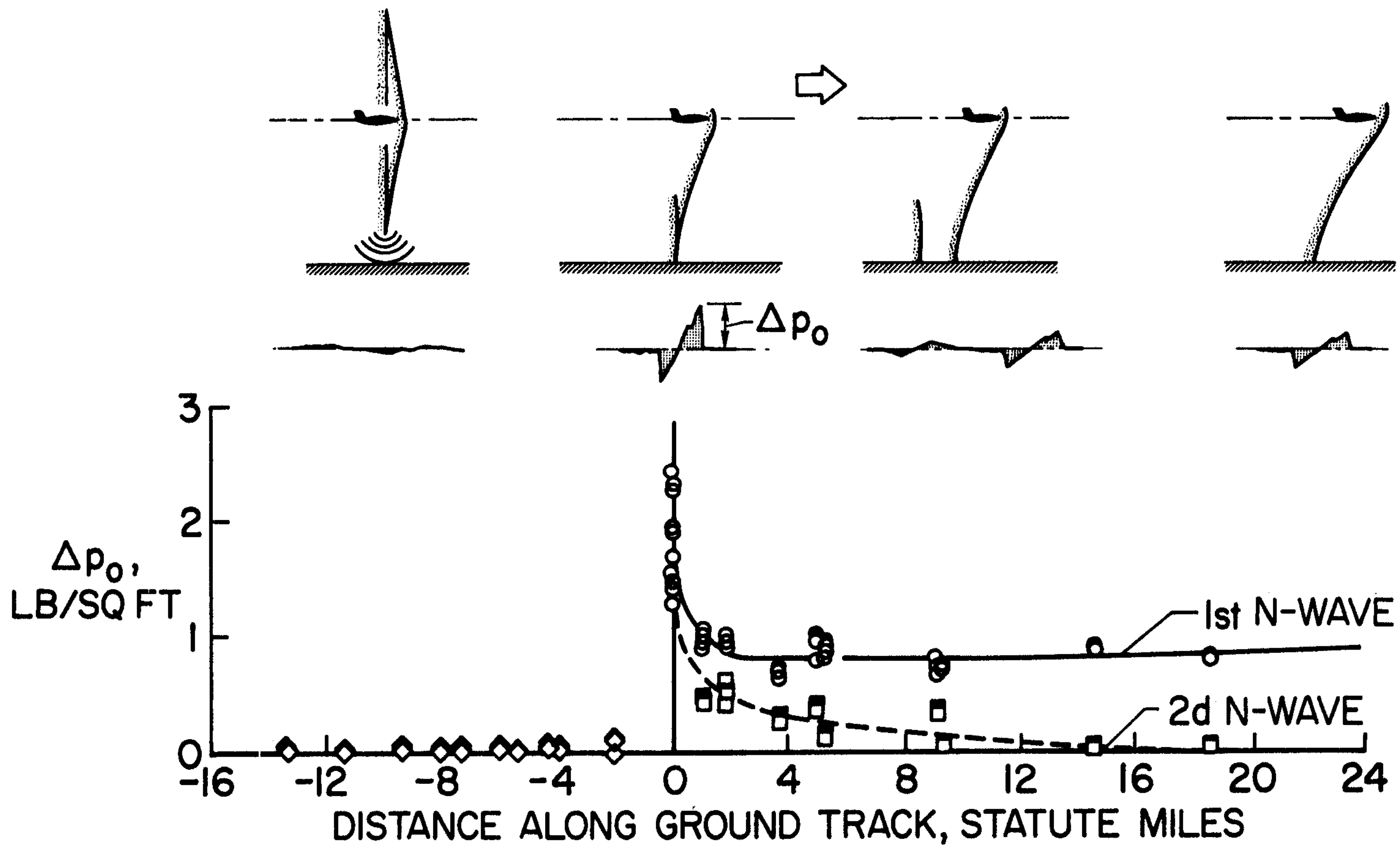


Figure 3.- Sonic-boom overpressure measurements along the ground track for an aircraft in accelerated flight.

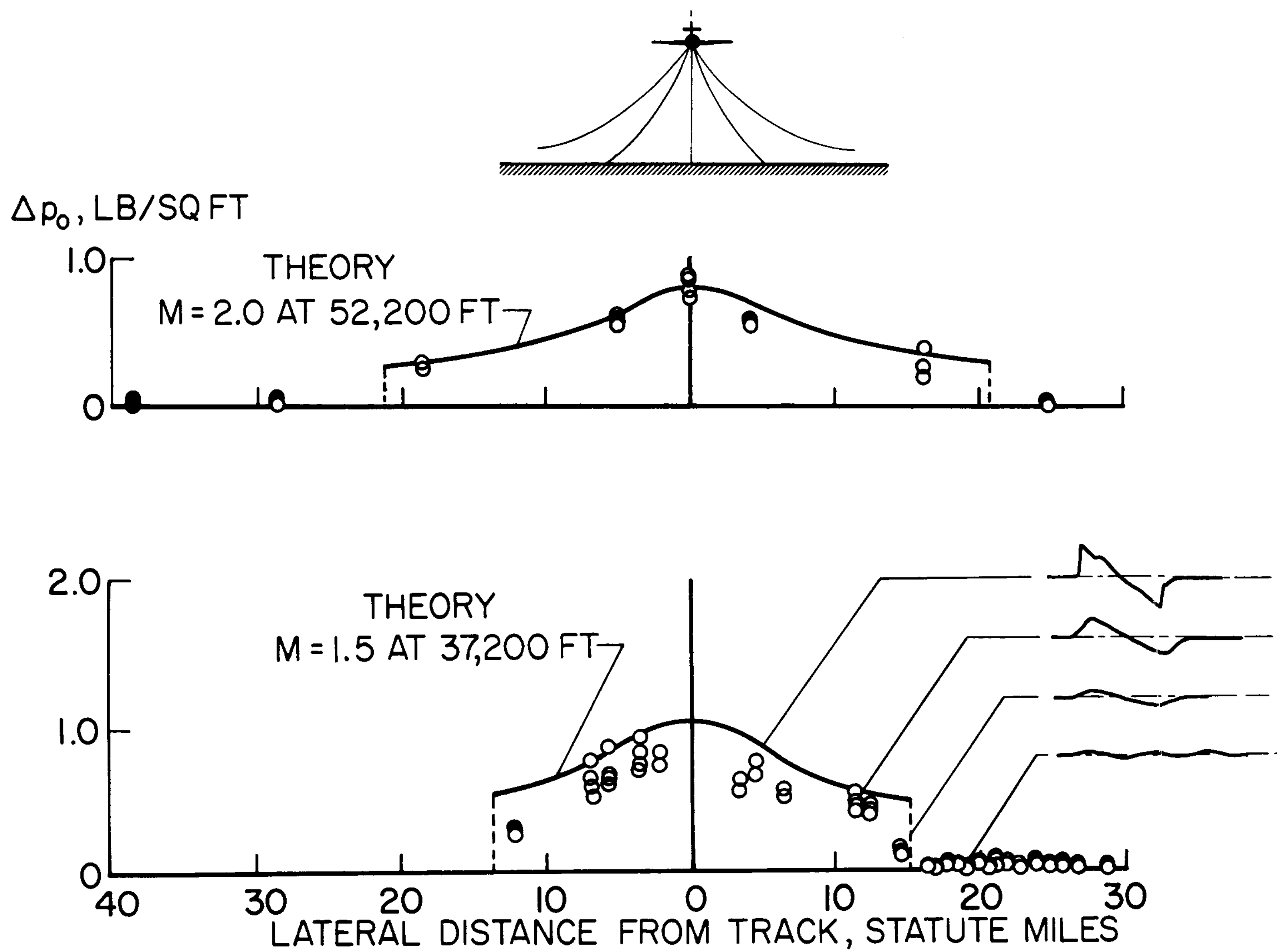


Figure 4.- Measured lateral spread patterns for a fighter aircraft at two different altitudes.

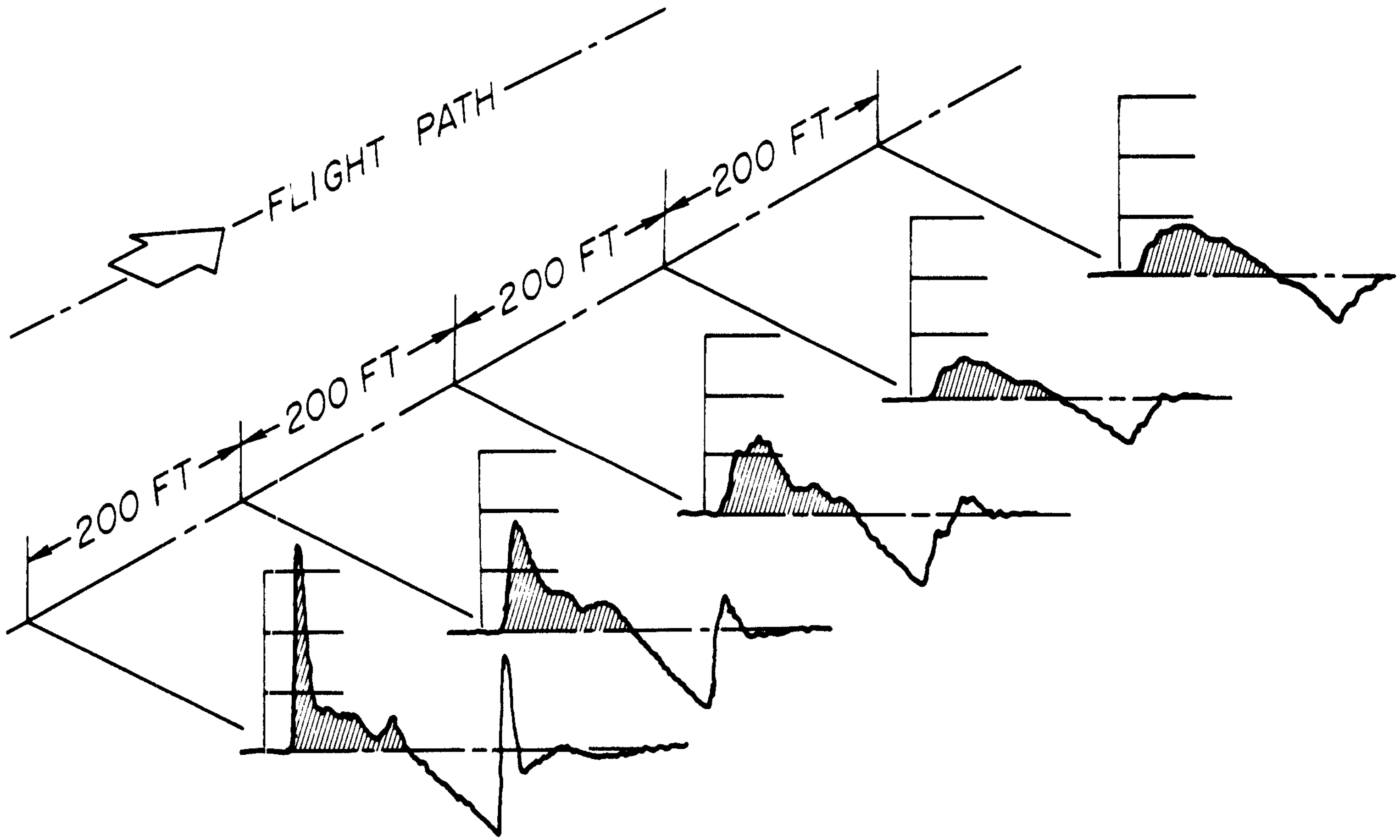


Figure 5.- Measured sonic-boom pressure signatures at several points on the ground track of a fighter aircraft in steady level flight at a Mach number of 1.5 and an altitude of 29,000 feet.

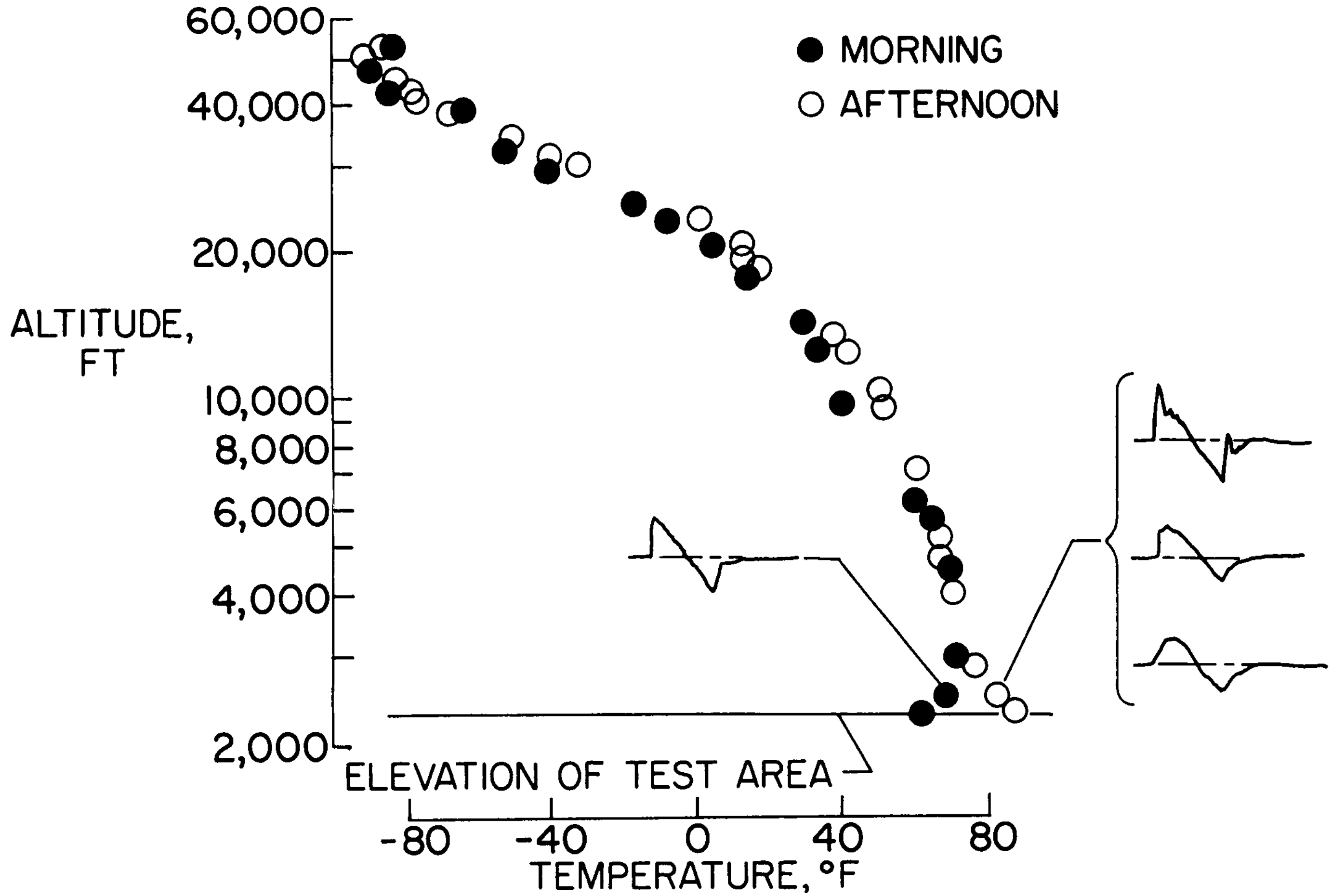
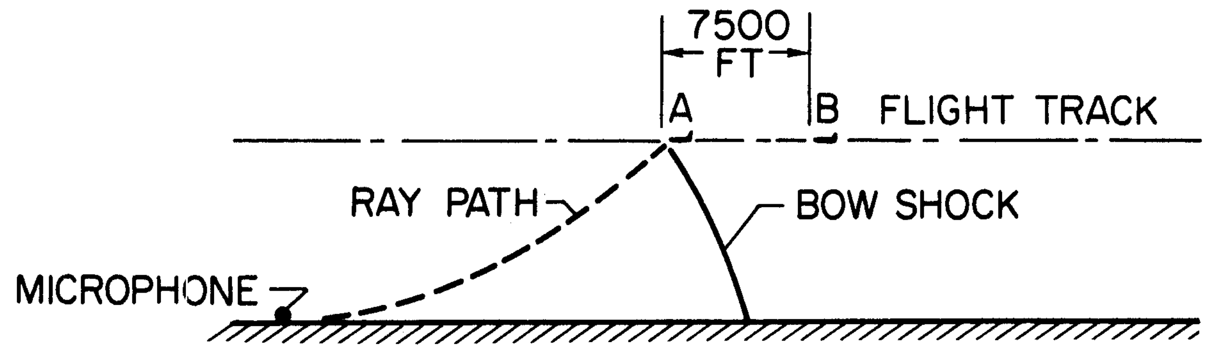
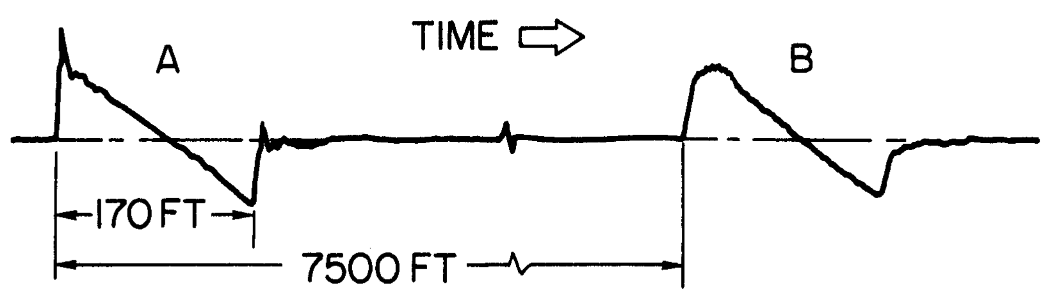


Figure 6.- Effect of temperature profile on measured sonic-boom pressure signatures.



(a) SCHEMATIC OF SHOCK FRONT AND RAY PATH



(b) SONIC BOOM GROUND PRESSURE SIGNATURES

Figure 7.- Variations in measured sonic-boom pressure signatures for two airplanes of the same type operating at the same flight conditions but at about a 5-second time interval.

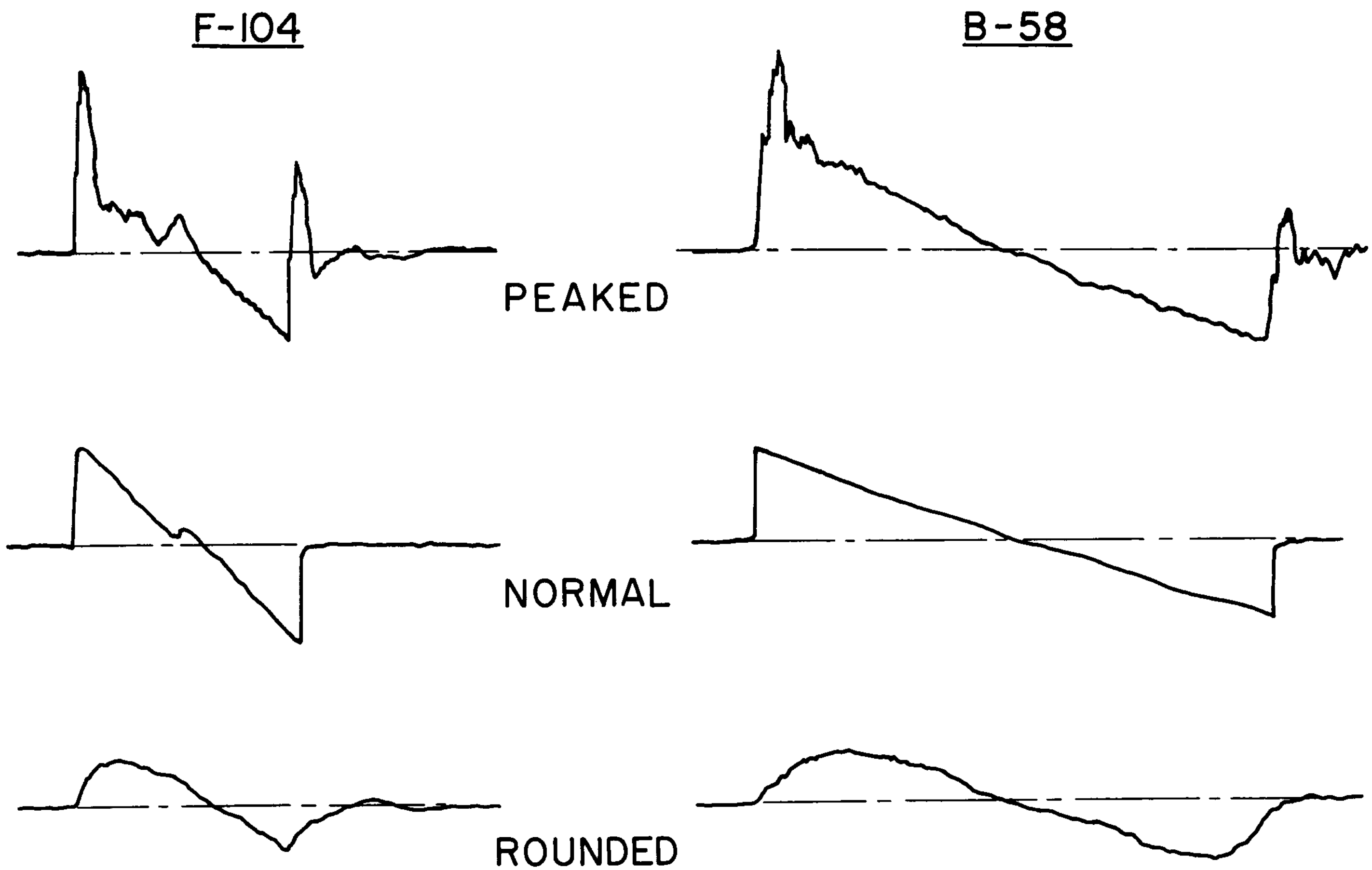


Figure 8.- Variations in sonic-boom measured signatures for fighter and bomber aircraft.

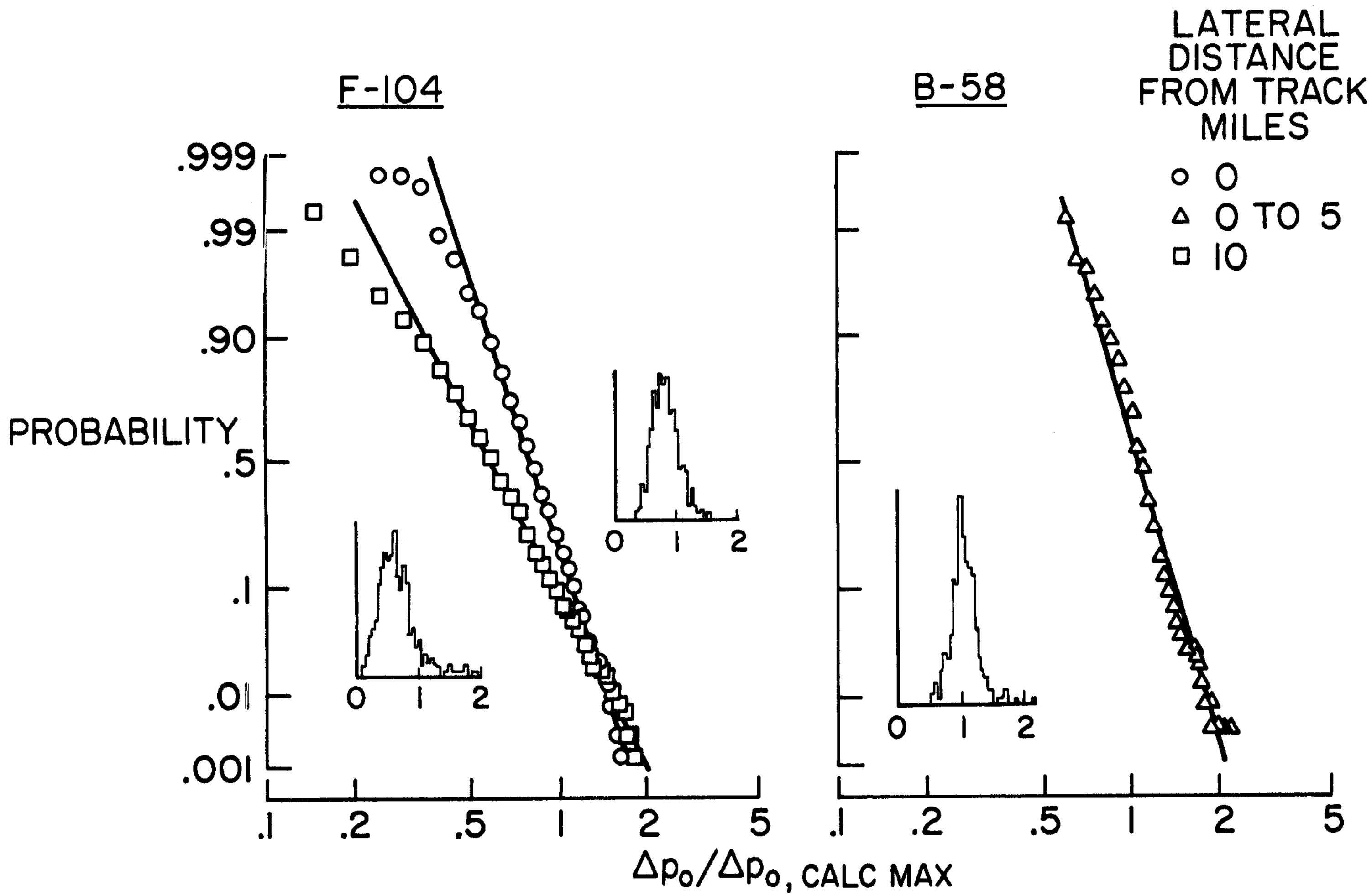


Figure 9.- Probability of equaling or exceeding a given value of the ratio of measured to calculated overpressures for fighter and bomber aircraft.

NASA-Langley, 1965